ATLANTIC MULTI-DECADAL VARIABILITY AND ITS CLIMATE IMPACTS IN CMIP3 AND CMIP5 MODELS

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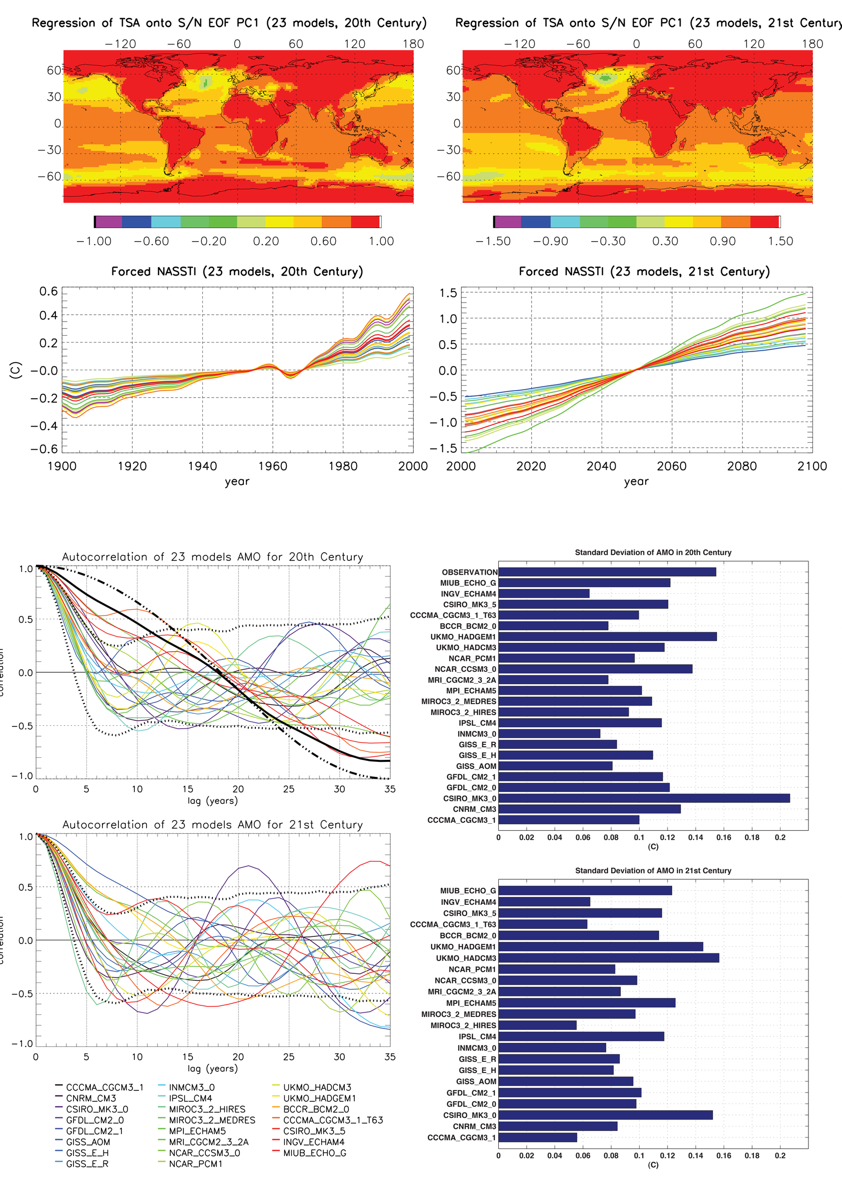
INTRODUCTION

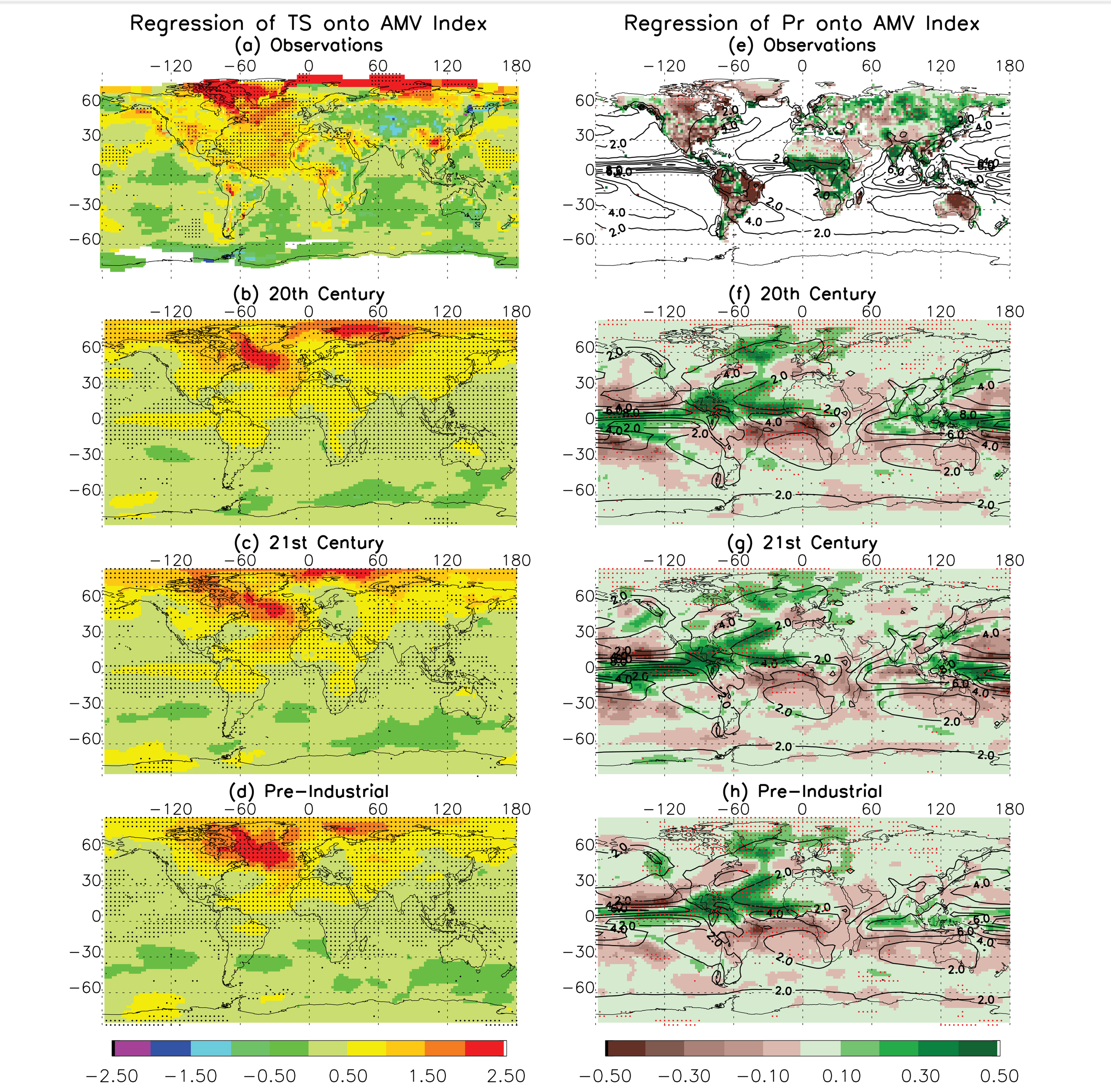
Atlantic Multi-decadal Variability (AMV), also known as the Atlantic Multi-decadal Oscillation (AMO), is characterized by a sharp rise and fall of the North Atlantic basin-wide sea surface temperatures (SST) on multi-decadal time scales. Widespread consequences of these rapid temperature swings are noted by many previous studies, such as the drying of Sahel in the 1960-70s and change in the frequency and intensity of Atlantic hurricanes. The central question is whether these observed climate fluctuations are indeed a consequence of the AMV. We address this issue by using the CMIP3 simulations for the 20th, 21st, and pre-industrial simulations with 23 models, and 12 CMIP5 models for the 20th Century. While models tend to produce AMV of shorter time scales (20-30 years) than observations, the spatial structure of the pattern and its impacts on precipitation are rather robust in models and observations. In addition, the CMIP5 models tend to agree more with observations than that in CMIP3. It confirms the strong impacts of AMV on Sahel rainfall and provides a clear physical mechanism for its impact (northward shifted Atlantic ITCZ). The main differences between CMIP3 and CMIP5 are in the tropical Pacific SST anomalies associated with AMV. The less robust climate impacts over North America and Indian monsoon region tend to be better defined in CMIP5 models due to the better representation of the tropical Pacific SST anomalies.

AMO definition in CMIP3 20th and 21st Century Simulations



We first applied Signal-to-Noise (S/N) maximizing EOF analysis to multi- model, multi-ensemble CMIP3 20th and 21st Century simulations. Shown here are the surface temperature regressions (top) and temporal projections of the North Atlantic SST onto the S/N PC1 for 20th (left) and 21st (right) Centuries.

We then subtract the forced component above from the area-averaged North Atlantic SST index in each model to obtain the AMV indices. Left: Autocorrelation of AMV indices in models (color lines) and observations (black line) with lags from zero to 35 years for 20th Century (top) and 21st Century (lower). Black dot-dashed line is the auto-correlation when calculated for a perfect sine function with a period of 70 years, and the dotted black lines represent the 5% significance intervals at each lag based on autocorrelations of the white noise time series. The keys for the color lines are indicated at the bottom on the left. Right: The corresponding amplitudes for the AMV indices.



Annual mean global surface temperature regression onto the AMV indices for (a) observations, (b) 20th Century, (c) 21st Century, and (d) Preindustrial CMIP3 model simulations. (e)-(h) same as (a)-(d), but for precipitation. Stippling in (a) and (e) indicates 95% confidence level based on Monte Carlo test, in (b), (c), (f), and (g) indicates 18 out of 23 models showing the same sign regression coefficients, in (d) and (h) indicates 16 out of 20 models showing the same sign regression coefficients. Contours in right panels are for climatological precipitation contoured at 2 mm/day intervals.

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CMIP3 vs. CMIP5 Models Used

CMIP5/Historical

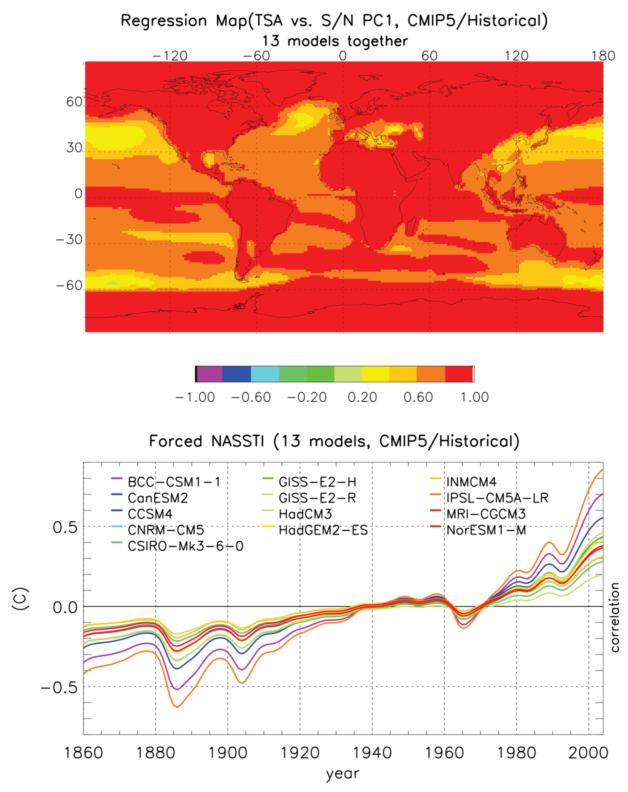
Model	ensembel members	Data resolution
bcc-csm1-1	3	Gaussian grid (nx=128, ny=64)
CanESM2	5	Gaussian grid (nx=128, ny=64)
CCSM4	6	1.25X0.9424084 (nx=288, ny=192)
CNRM-CM5	9	Gaussian grid (nx=256, ny=128)
CSIRO-Mk3-6-0	10	Gaussian grid (nx=192, ny=96)
GISS-E2-H	5	2.5X2.0 (nx=144, ny=90)
GISS-E2-R	5	2.5X2.0 (nx=144, ny=90)
HadCM3	1	3.75X2.5 (nx=96, ny=73)
HadGEM2-ES	4	1.875X1.25 (nx=192, ny=145)
inmcm4	1	2.0X1.5 (nx=180, ny=120)
IPSL-CM5A-LR	4	3.75X1.894737 (nx=96, ny=96)
MRI-CGCM3	5	Gaussian grid (nx=320, ny=160)
NorESM1-M	3	2.5X1.894737 (nx=144, ny=96)

IPCC-AR4

Model	resolution
BCCR_BCM2_0	Gaussian grid (nx=192, ny=96)
CCCMA_CGCM3_1	Gaussian grid (nx=192, ny=96)
CCCMA_CGCM3_1_T63	Gaussian grid (nx=128, ny=64)
CNRM_CM3	Gaussian grid (nx=192, ny=96)
CSIRO_MK3_0	Gaussian grid (nx=192, ny=96)
CSIRO_MK3_5	Gaussian grid (nx=192, ny=96)
GFDL_CM2_0	2.5 x 2.0 (nx=144, ny=90)
GFDL_CM2_1	2.5 x 2.0 (nx=144, ny=90)
GISS_AOM	4.0 x 3.0 (nx=90, ny=60)
GISS_E_H	5.0 x 4.0 (nx=72, ny=46)
GISS_E_R	5.0 x 4.0 (nx=72, ny=46)
INGV_ECHAM4	Gaussian grid (nx=128, ny=64)
INMCM3_0	5.0 x 4.0 (nx=72, ny=45)
IPSL_CM4	3.75 x 2.5 (nx=96, ny=72)
MIROC3_2_HIRES	Gaussian grid (nx=320, ny=160)
MIROC3_2_MEDRES	Gaussian grid (nx=128, ny=64)
MIUB_ECHO_G	Gaussian grid (nx=96, ny=48)
MPI_ECHAM5	Gaussian grid (nx=192, ny=96)
MRI_CGCM2_3_2A	Gaussian grid (nx=128, ny=64)
NCAR_CCSM3_0	Gaussian grid (nx=256, ny=128)
NCAR_PCM1	Gaussian grid (nx=128, ny=64)
UKMO_HADCM3	3.75 x 2.5 (nx=96, ny=73)
UKMO_HADGEM1	1.875 x 1.25 (nx=192, ny=145)

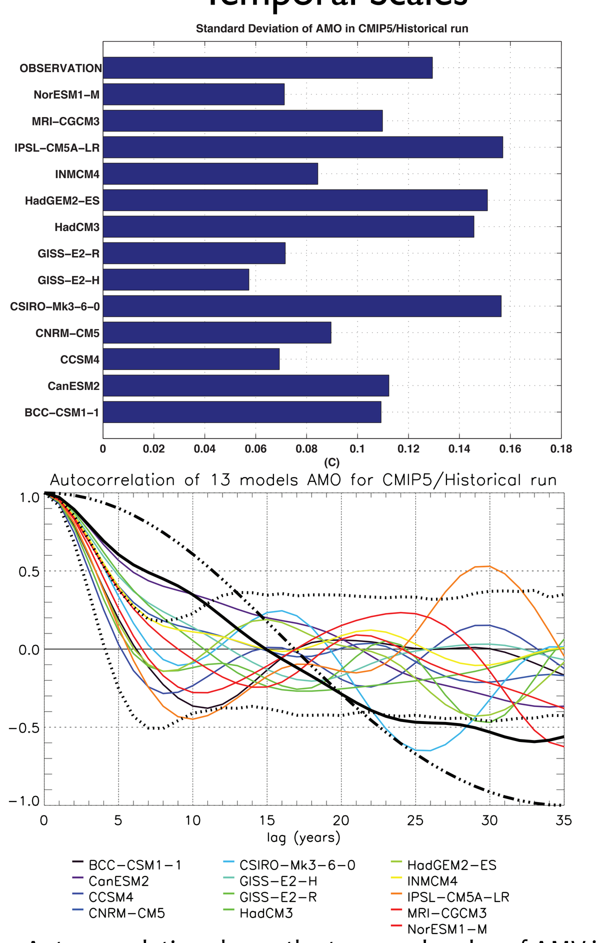
Forced vs. Natural Atlantic SST Variability in CMIP5

S/N EOF for 13 CMIP5 Models



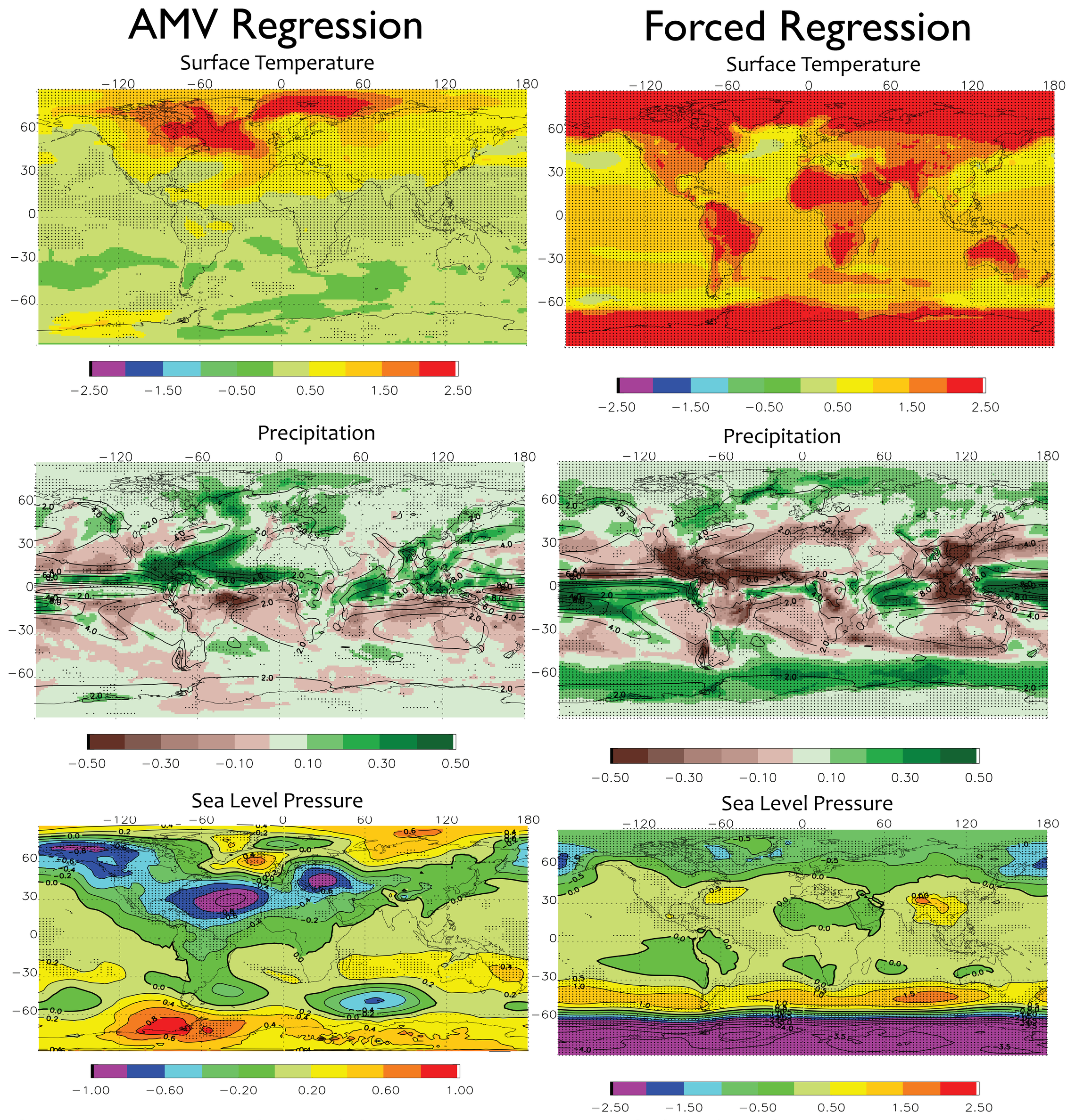
Signal-to-Noise (S/N) maximizing EOF analysis applied to 13 available models, 57 ensemble members of the historical (1860-2005) CMIP5 simulations. Shown here are the surface temperature regressions (top) and temporal projections of the North Atlantic SST onto the S/N PC1 for 13 models.

AMV Amplitude and Temporal Scales



Auto correlation shows the temporal scales of AMV in CMIP5 are shorter than its 20th Century observational counterparts, similar to that in CMIP3. The AMV amplitudes, on the other hand, are similar in observations, CMIP3 and CMIP5.

AMV Regression / Forced Regression

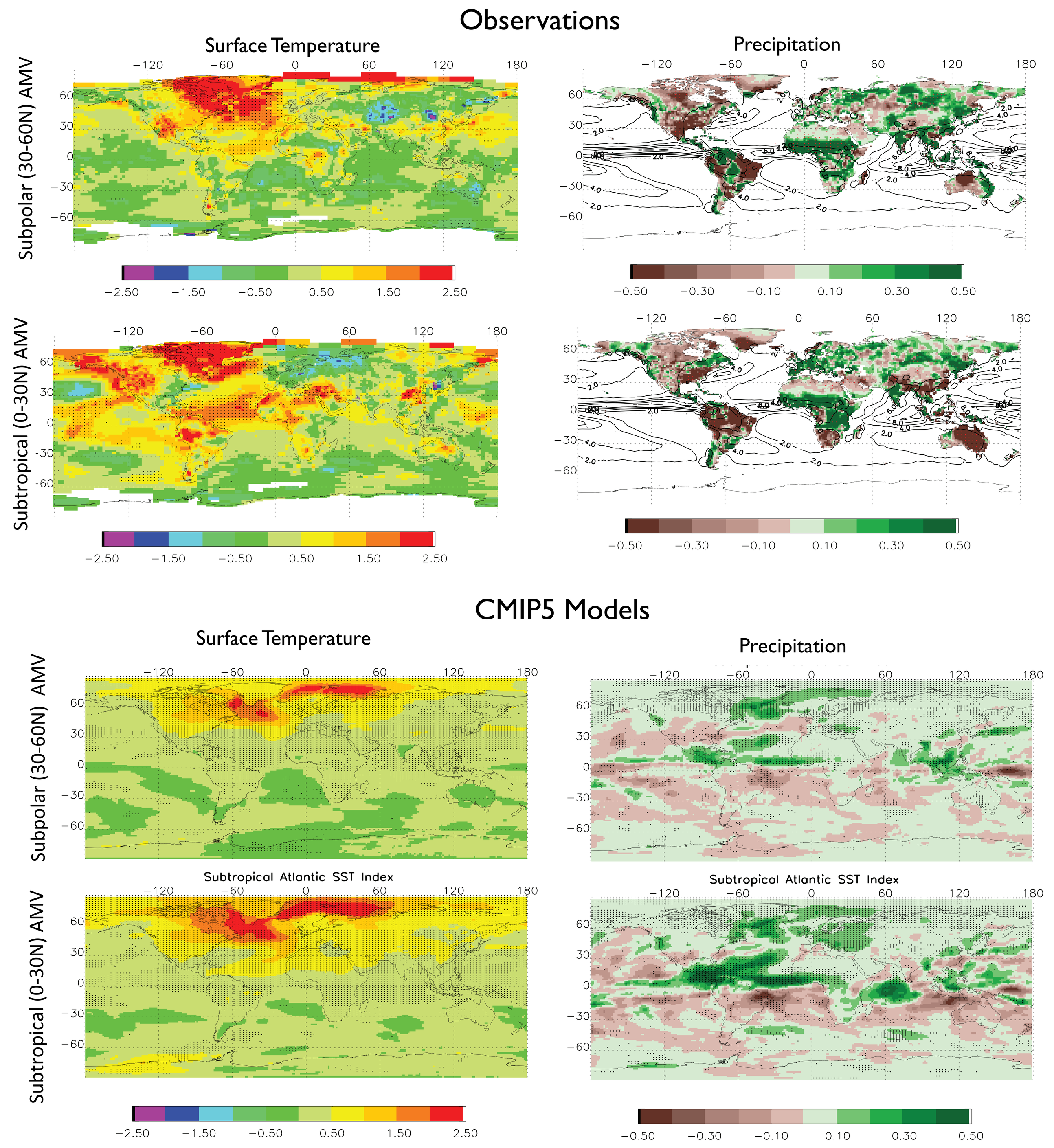


Left: Annual mean multi-model average regression of global surface temperature, precipitation, and sea level pressure onto the AMO time series. Stippling indicates at least 10 out of 12 models showing the same sign. Right: same as left, but for the forced regression.

Comparison between Forced and Natural North Atlantic SST variability:

- Distinctive SST pattern over the North Atlantic - warmer North Atlantic than South Atlantic in AMV+ phase and opposite for forced component.
- Extremely dry tropical North Atlantic and to some extent, the Sahel, in forced precip versus wetter condition over these regions in AMV+.
- Southwest North America and Northeast South America getting dryer in AMV+ and forced precip.

AMV Subpolar vs. Subtropical SST Impacts

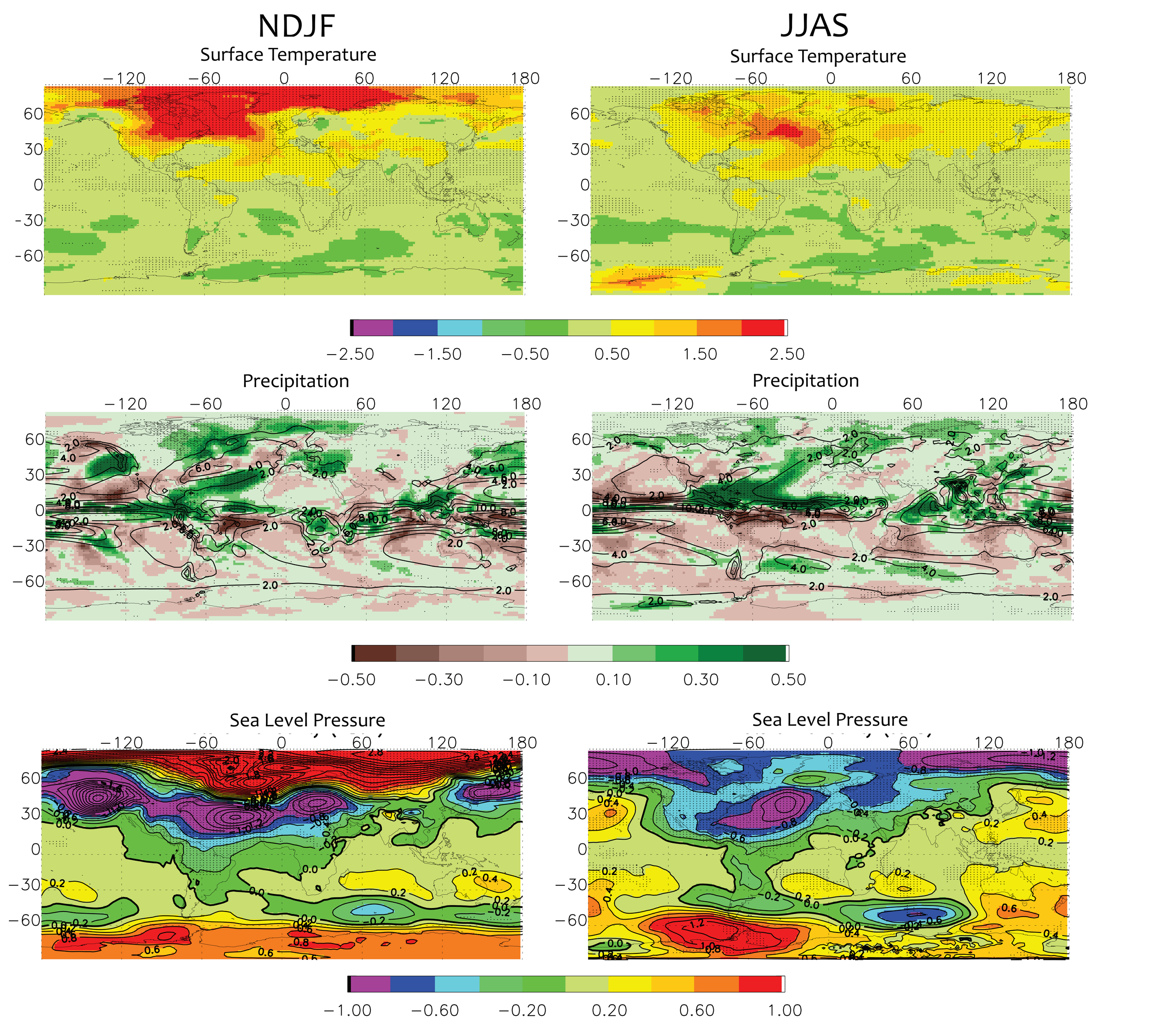


We first computed the subpolar (30N-60N) and subtropical (0-30N) SST indices in the same way as the AMV index. Then regress surface temperature and precipitation onto those indices. Stippling regions indicate 10 out of 12 models showing the same sign regression.

SUMMARY

- In general, the AMV patterns are similar in CMIP3 and CMIP5 in both spatial structures and temporal scales.
- The wetting trend over Sahel and drying over North America during AMV+ are enhanced in CMIP5. The Indian monsoon also tend to be stronger during AMV+ in CMIP5, closer to observations.
- Differences between CMIP3 and CMIP5 may be due to the reduced eastern tropical Pacific SST warming associated with AMV+ in CMIP5 compared to CMIP3 –again closer to that in observations. The reason for this improvement is not clear.
- Both the subtropical and subpolar components of AMV contribute to the precipitation anomalies. The CMIP5 models tend to have a weaker subpolar SST impacts compared to that in observations.
- Depending on the phases of AMV, some regions may experience aggravated effect of global climate change, such as the drying of Sahel during AMV- and the drying of Southwest North America and Northeast South America during AMV+.

Seasonal AMV Regression in CMIP5



These regression patterns show the seasonal cycle of the AMV and associated precipitation and sea level pressure anomalies. The Sahel rainfall anomalies and the Indian monsoon anomalies are mainly in the summer season, while the North and South American drying during AMV+ occurs in both winter and summer. There is a strong negative NAO and reduced Atlantic storm track rainfall associated with AMV+ during winter. (Stippling indicates 10 out of 12 models showing the same sign regression.)